Name: ______________________________________ Date: ________________________

Student Exploration: Equilibrium and Concentration

Vocabulary: chemical equilibrium, concentration, equilibrium, equilibrium constant, reaction quotient, reversible reaction

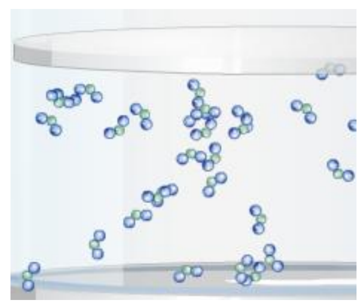
Prior Knowledge Questions (Do these BEFORE using the Gizmo.)
Gary has $5,000 in his bank account and earns a modest salary. Every month he pays for rent, food, utilities, and entertainment.

A. How will Gary's account change if he saves more than he spends? _________________

B. How will Gary's account change if he spends more than he saves? _________________

C. What happens if Gary spends exactly as much as he saves? _____________________

Gizmo Warm-up
If Gary spends exactly as much as he earns, his savings will be in **equilibrium**. Equilibrium occurs when two opposing processes occur at the same rate, leading to no net change. In the *Equilibrium and Concentration* Gizmo™, you will investigate how equilibrium can occur in chemical reactions.



To begin, check that **Reaction 1** is selected. Set **Moles NO_2** to 8 and **Moles N_2O_4** to 0.

1. Click **Play** (▶) and observe the colliding molecules. What do you notice? _______________

   ____

   In the Gizmo, a blue flash appears every time two reactants combine to form a product. A red flash appears every time a product dissociates into reactants.

2. Click **Reset** (⮌), and set **Moles NO_2** to 0 and **Moles N_2O_4** to 8. Click **Play**.

   What do you notice now? ____

3. When a reaction can proceed in either direction, it is a **reversible reaction**. Based on what you have observed, is the synthesis of NO_2 into N_2O_4 a reversible reaction? Explain.

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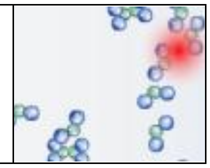
Activity A: **Reversible reactions**	Get the Gizmo ready: • Click **Reset**. **Reaction 1** should be selected. • Set **Moles NO_2** to 8 and **Moles N_2O_4** to 0. • Move the ***Sim. speed*** slider all the way to the right.	

Question: What are the characteristics of reversible reactions?

1. Predict: Suppose you began with 8 moles of NO_2 in the chamber. What do you think will happen if you let the reaction go for a long time? ___________________________________

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2. Test: Click **Play**. Select the **Bar Chart** tab and check that **Moles** is selected. Observe the bar chart for about 30 seconds. As time goes by, what do you notice about the bars representing moles NO_2 and moles N_2O_4?

   ____

3. Observe: Click **Pause** (⏸). Select the **Graph** tab. Click the (–) zoom control on the horizontal axis until you can see the whole graph. What do you notice?

   ____

   This situation, in which the overall amounts of reactants and products does not change significantly over time, is called a **chemical equilibrium**.

4. Record: On the **Bar Chart** tab, turn on **Show data values**. How many moles of NO_2 and N_2O_4 are there right now? Moles NO_2 __________ Moles N_2O_4 __________

5. Calculate: Suppose all the NO_2 molecules were synthesized into N_2O_4. Given the equation $2NO_2 \leftrightarrow N_2O_4$, how many moles of N_2O_4 would be produced? _______________

6. Experiment: Click **Reset**. On the **Initial Settings** tab, set **Moles NO_2** to 0 and **Moles N_2O_4** to 4. Click **Play**. Click **Pause** when the bars of the **Bar Chart** stop moving very much.

   A. List the current amounts of each substance: Moles NO_2 ______ Moles N_2O_4 ______

   B. How do these results compare to starting with 8 moles of NO_2? ________________

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(Activity A continued on next page)

Activity A (continued from previous page)

7. Summarize: How do the initial settings affect the equilibrium amounts of each substance?

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8. Set up the Gizmo: Click **Reset** and select the **Experiment** tab on the left. On the **Initial Settings** tab on the right, select **Reaction 2**. Set **Moles NO** to 5, **Moles NO_2** to 5, and **Moles N_2O_3** to 0. What are the reactants and product of this reaction?

   Reactants: ___________ ___________ Product: ___________

9. Observe: Recall that a blue flash appears every time two reactants combine to form a product. A red flash appears every time a product dissociates into reactants. Click **Play**.

   A. At first, do you notice more blue flashes or red flashes? _________________________

   B. What do you notice about the frequency of blue and red flashes as time goes by?

   ____

   C. Click **Reset**. This time, start the experiment with 0 moles of NO and NO_2, and 5 moles of N_2O_3. Click **Play**. What do you notice about the red and blue flashes now?

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10. Explain: Think about how the numbers of blue and red flashes reflect the rates of the forward (reactants → products) and reverse (products → reactants) reactions.

   A. What happens to the rate of the forward reaction as the reactants are consumed?

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   B. What happens to the rate of the reverse reaction as the products are produced?

   ____

   C. Why do reversible reactions *always* result in chemical equilibria? ________________

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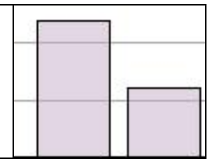
Activity B: The equilibrium constant	Get the Gizmo ready:	
Activity B: **The equilibrium constant**	<u>Get the Gizmo ready</u>: • Click **Reset**. Select **Reaction 1**. • Set **Moles NO_2** to 2 and **Moles N_2O_4** to 7.	

Introduction: When investigating the rates of reactions, it often is useful to consider the **concentrations** of reactants rather than the total number of moles. Concentrations are often expressed in moles per liter, or mol/L. Brackets are used to signify concentration. For example, "$[H_2]$ = 5.0 M" means the concentration of hydrogen gas in a chamber is 5.0 moles per liter.

Question: What are the characteristics of reactions in equilibrium?

1. <u>Record</u>: On the **Bar Chart** tab, select **Concentration**. Check that **Show data values** is on. If necessary, use the arrows to adjust the scale of the chart.

   A. What are the current concentrations of each compound?

   $[NO_2]$ ___________ $[N_2O_4]$ ___________

   B. Click **Play** and wait for equilibrium to become established. Click **Pause**. What are the approximate equilibrium concentrations?

   $[NO_2]$ ___________ $[N_2O_4]$ ___________

2. <u>Calculate</u>: The value K_c represents the ratio of products to reactants in a reaction at equilibrium. The greater the amount of products relative to reactants, the higher the resulting value of K_c. For a general reaction between gases: aA(g) + bB(g) ↔ cC(g) + dD(g), K_c is calculated as follows:

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

   For the current reaction, $2NO_2 \leftrightarrow N_2O_4$, we have:

$$K_c = \frac{[N_2O_4]}{[NO_2]^2}$$

   Based on the current concentrations of NO_2 and N_2O_4, what is K_c? ____________________

   Show your work here:

(Activity B continued on next page)

Activity B (continued from previous page)

3. Gather data: Experiment with a variety of initial concentrations of NO_2 and N_2O_4. For each set of initial concentrations, use the Gizmo to determine the equilibrium concentrations of each substance. In the last column, find K_c for that trial. Run three trials for each set of initial conditions.

Initial $[NO_2]$	Initial $[N_2O_4]$	Equilibrium $[NO_2]$	Equilibrium $[N_2O_4]$	K_c

4. Calculate: Find the average value of K_c for each set of three trials.

   Trials 1-3: __________ Trials 4-6: __________ Trials 7-9: __________

5. Analyze: What do you notice about the values of K_c? ______________________________

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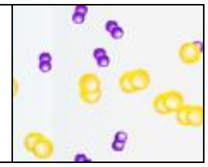
   In general, the value of K_c will be constant for a given reaction at a constant temperature, no matter the starting concentrations. That is why K_c is known as the **equilibrium constant**. In this Gizmo, the values of K_c will vary somewhat because there is a very limited number of molecules in the chamber.

6. On your own: Use the Gizmo to find K_c for **Reaction 4**: $H_2 + I_2 \leftrightarrow 2HI$. Collect data at least 10 times and average your results to get the best approximation of K_c. Show your data and work on a separate sheet of paper.

   (Hint: Because of the coefficient "2" in front of HI, you will have to square the concentration of HI to find K_c.)

   K_c = __________

Activity C: **Reaction direction**	Get the Gizmo ready: • Click **Reset**. Check that **Reaction 4** is selected. • Set **Moles H_2** to 5, **Moles I_2** to 5, and **Moles HI** to 3.	

Introduction: For a reversible reaction with equilibrium constant K_c, it often is useful to know in which direction the reaction will proceed given the starting amounts of reactants A and B and products C and D. This is done by calculating the **reaction quotient**, Q_c:

$$Q_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

Question: How can you predict the direction of a reversible reaction?

1. List: Select the **Bar Chart** tab. What are the initial concentrations of each substance?

   $[H_2]$ ________ $[I_2]$ ________ [HI] ________

2. Calculate: Use the equation above to find Q_c for the current reaction.

   A. What is the current value of Q_c? ___________

   B. In activity B, what value of K_c did you arrive at for this reaction? ___________

   C. How does Q_c compare to K_c? ____

3. Analyze: Recall that Q_c is equal to the ratio of product concentrations to reactant concentrations.

   A. If there is an excess of products, will Q_c be greater than or less than K_c? ___________

   B. If there is an excess of reactants, will Q_c be greater than or less than K_c? __________

   C. In the current situation, is there an excess of products or reactants? ______________

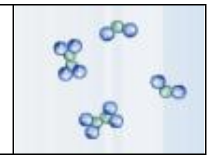
   Explain: ____

   D. When the reaction begins, do you expect [HI] to increase or decrease? ____________

   Explain: ____

4. Test: Click **Play**. What happens to [HI]? ____

   ____

Extension: **Equilibrium calculations**	<u>Get the Gizmo ready</u>: • Click **Reset**. Select **Reaction 1**. • Set **Moles NO_2** to 0 and **Moles N_2O_4** to 6.	

Goal: Given K_c and initial concentrations, calculate equilibrium concentrations.

1. <u>List</u>: Select the **Bar Chart**. What is the initial concentration N_2O_4? $[N_2O_4]_{initial}$ = _______

2. <u>Experiment</u>: Click **Play** and wait for a few seconds. Click **Pause** before equilibrium is reached.

   A. What is the current concentration of N_2O_4? $[N_2O_4]$ = _______

   B. How much has the concentration of N_2O_4 gone down? _______

   C. What is the current concentration of NO_2? $[NO_2]$ = _______

   D. In general, if $[N_2O_4]$ is reduced by *x*, how much does $[NO_2]$ increase? ____________

3. <u>Manipulate</u>: Begin with the general equation for K_c: $K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$.

   A. What is the equation for K_c for the reaction $2NO_2 \leftrightarrow N_2O_4$? K_c =

   B. In this experiment, the initial concentration of NO_2 is zero. If the concentration of N_2O_4 is reduced by *x* at equilibrium, the equilibrium concentration of NO_2 is equal to *x*. Substitute the following values into the equation you wrote in step A:

   $[N_2O_4] = ([N_2O_4]_{initial} - x)$ $[NO_2] = x$

   K_c =

   C. In activity A, you discovered that K_c for this reaction was close to 0.042. Substitute this value and the initial concentration of N_2O_4 into your equation.

   =

   D. Rearrange the terms of your equation to form a quadratic equation in the form $ax^2 + bx + c = 0$.

   = 0

(Extension continued on next page)

Extension (continued from previous page)

4. Solve: Because the equation is in the form $ax^2 + bx + c = 0$, you can use the quadratic formula (shown below) to solve for x. Ignore negative solutions because the concentrations cannot be negative. Show your work.

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

5. Predict: Based on the value for x, what do you expect the equilibrium concentrations of NO_2 and N_2O_4 to be?

   $[NO_2]$ ___________ $[N_2O_4]$ ___________

   Check your work by solving for K_c using $K_c = \frac{[N_2O_4]}{[NO_2]^2}$ K_c = ___________

   If you don't get the correct value of K_c, recheck your work.

6. Test: Click **Play** and wait for equilibrium to be established. What are the actual equilibrium values of each substance?

   $[NO_2]$ ___________ $[N_2O_4]$ ___________

   How close were these results to your predicted results? ______________________________

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7. Challenge: Suppose you begin with 6 moles of NO_2 and 5 moles of N_2O_4. Assuming a value for K_c of 0.042, predict the equilibrium concentrations of NO_2 and N_2O_4. (Use the Gizmo to determine the initial concentrations.) Show your work on a separate sheet of paper. After you have made your predictions, click **Play** and record the experimental results.

   Predicted: $[NO_2]$ ________ $[N_2O_4]$ ________

   Experimental: $[NO_2]$ ________ $[N_2O_4]$ ________